

THE MOON AT THE HANDS OF THE INVESTIGATORS

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The Moon at the Hands of the Investigators

How does a young French researcher become a N.A.S.A. investigator, a holder of Moon samples as well as Soviet Moon dust?

Back from the service I entered the Laboratory of Chemistry and Physics at the Faculty of Sciences of Paris, and from there I had the exceptional opportunity for a young French scientist to meet an American researcher, whom I would not hesitate to qualify as a genius according to my criteria: Professor Walker of Washington University who came to work in France for one year. In 1962, at the beginning of the Apollo program, he thought about using the Moon's surface as a gigantic detector of solar nuclear particles. In order to be prepared for these experiments, we began to perform artificial irradiations of earth samples, then we studied the marks of natural irradiation in extraterrestrial samples such as meteorites. In that way we elaborated our methods from 1962 till 1969. In September of that year, we were ready and received our first samples. We were lucky to have good results. I was working then as an investigator in Walker's group. In 1970 new methods were perfected: methods of which I would not have thought in the beginning but which I helped to develop.

Let us move from the particular to the general. How does N.A.S.A. choose its investigators?

It seems to me that two ideas prevailed in their policy, competition and diversity. Competition comes first. In France it is still an ill-assimilated notion. The ruling circles tend to distribute the programs by avoiding competition and seeing that everyone receives a role according to his reputation.

In diplomatic terms, are you describing the Mandarin system?

Well, whatever it is, the procedure is different in the United States. N.A.S.A. nominated a commission of eminent and completely independent scientists. They examined all the propositions without trying to determine if the author was an expert or not.

¹ NRS Research Director.

I would like you to clear up a point. Who receives the moon samples. An organization or an individual?

An individual of course. We are in the United States, not in France.

But many ridiculous propositions must have been sent.

Of course. Some wanted to look for traces of intelligent activities on the moon. But this commission of scientists formed an impassable barrier. Therefore, there was competition between projects, but also competition resulting in assigning similar studies to several groups simultaneously.

At the present time, are other researchers doing research comparable to yours?

Certainly, but with slightly different methods.

Are foreigners disadvantaged with respect to Americans in this distribution?

Absolutely not, it is quite the contrary. There are so many excellent teams in the United States that foreigners must be given more chance than Americans to maintain a real international characteristic in the program. I heard American researchers tell me that everything would be easier for them if they were foreigners.

Let us drop competition and distribution and consider the other aspect: multidisciplinary. At first it does not seem to be an obvious idea. We should rather be tempted to consider the study of Moon rocks as a specialist's affair.

It is not only a research of multidisciplinary type, but I think that it is the best example of it; and on the other hand the most perfect because of the way the program was conducted.

To observe a Moon sample properly you have to be at the same time a mineralogist, a petrographer, a specialist in Solar wind, in organic chemistry, in nuclear physics, etc. As the same individual cannot possess all these qualifications, cooperation between researchers has to be created. This idea became so strong that N.A.S.A. wishes that the researchers would form a consortium. Therefore, in the international consortium to which I belong there is an organic chemist studying the problem of the origin of life.

Origin of life on the Moon?

Of course, but it is more precisely the problem of the origin of basic elements of the living cell and this means all the astrochemical discoveries. As you know, scientists have found organic molecules in interstellar space. Up to now we thought that the synthesis of organic molecules necessary for the appearance of life was due to a chemical process in an aqueous environment, the primitive liquid. But astrochemistry reveals a "spatial" chemistry. Some think that interstellar dust is the preferential site of this chemical reaction. In this case Moon dust could have fulfilled a similar role with the sole difference that organic molecules could not exist in a lunar environment. It is a completely new but very interesting research. Let us come back to our consortium. In addition to this chemist, we have a petrographer-mineralogist working on the origin of minerals, their evolution, the erosion of rocks, etc. A physicist in rare gases pursues studies on the nature of solar wind. Professor Dolffus studies lunar albedo, i.e. in short the reflecting power of the Moon. During and after this research he participated in the creation of a telescope able to photograph asteroids in the "Grand Tour" mission. For my part, I am interested in the history of the irradiation of Moon samples by former cosmic radiations of solar and galactic origin.

The collaboration is constant between all these researchers. They all need each other. A chemist is needed to know if carbon dates from the beginning or results from contamination, a petrographer to explain the presence of spherules and to find proof of shocks, a mineralogist to know what lamellas of exsolution mean, a specialist in the physics of solids to know the irradiation effects on a solid substance, etc.

Such is the scientific aspect. Let us talk about procedure and security. You have very strict rules to follow, extraordinary precautions to take when you become an owner of these samples.

A safe is required. The part of the laboratory where the samples are needs special locks, so that only the persons entitled to work on these samples may enter, for the nomination covers at the same time the chief investigator and the co-investigators entitled to work with him. Any request for samples must include

precise indications of these security rules. Sometimes it results in ludicrous consequences.

For example, Berkley physicists wanted to look for superheavy elements in Moon rocks. Neutron detectors were to be placed around the samples and a possible disintegration of one of these bodies by emitted neutrons was to be observed. To make this experiment successful, they had concluded that they had to take all the Moon rocks brought back on Earth to a tunnel near San Francisco. No longer was it several grams of rock that had to be protected in a lab, but several units of ten kilograms each. With such security rules it was impossible to pay the necessary guard according to security norms.

Such are the protection rules. You must also have very strict rules for the manipulation of these samples.

Yes, indeed, it really is a job for a grocer in 1900. We have large books where everything must be recorded. When we take the slightest milligram, we must record it, indicate what we did with it and the treatment it underwent. We must always keep it. We must always be able to give the sample back. If it has been diluted in 10 liters of solvent, then 10 liters of solvent must be given back if necessary. As a rule the sample is lent for three months. But an extension is requested every three months, to be able to pursue the experiments.

But you are not given a sample at random, are you?

Of course not; each sample is indexed, verified, photographed, presented with a commentary.

Real catalogues of Moon rocks exist, don't they?

Yes, these catalogues are well set up and kept up to date.

But you also possess Soviet samples? How did the Russians proceed?

Less information is given in this field. They seem to have adopted an opposite policy. Instead of distributing the samples in the scientific community according to the offers made, they adopted a much more centralized method. They planned the research to be done. A specialized laboratory in Moscow seems to assume most of the responsibilities in this field. They asked foreign research-

ers to perform certain research mentioned in their program and for which they were not as well equipped. Therefore the procedure would be rather the reverse. You offer the American your services, the Soviets ask for your services. But, when the work is done, you remain free to do other experiments if you want to.

Let us go back to the research you conducted on Moon samples. They will help us to grasp the problems occurring in a concrete case.

The idea was the following. The lunar surface is bare, exposed to the spatial environment, since there is no atmosphere. The whole Solar System is filled with particles of very different energies. Most of them come from the Sun. These particles reach the lunar surface directly, for in addition to the absence of an atmosphere, there is no magnetic field to deflect them. They must leave marks there. The particles of minerals forming this surface are like photographic plates recording "solar breath". Let us suppose now that the Moon soil is periodically turned over. We do not have only one layer, but a stack of layers, constituting in a word the archives of solar activity. If the latter has varied, the grains of Moon dust will not be uniformly marked. This is the principle, in highly schematic form.

To make it work, the solar irradiation of each particle must neither be too strong, nor too weak. We were incredibly lucky that it took place exactly at the level where our methods can be used under good conditions. The Moon was an ideal archivist. With our methods we were able to affirm that the rhythm of erosion seemed to be one millimeter for each million years on the Moon. If this is entirely correct, solar radiation must have been weak in the past.

Let us talk about these methods in detail.

They consist in considering each particle of Moon dust as a photographic plate. If we expose such a plate to the bombardment of ions with a certain energy, they will cause damage as they pass through the "emulsion". When we observe the plate later, we will not find the projectile but the scar it left. The same thing occurs in Moon rock exposed to solar radiation.

It therefore is a question of finding micro-scars left by solar radiation on lunar material.

Yes and no. The sensitivity of the methods has to be strictly considered. It is obvious that the larger the scar, the heavier and the more accelerated the ion is. With our 1969 methods only scars of a certain magnitude could be seen; about one micron or more. Under these conditions we studied the scars left by iron ions which are by far, the most numerous heavy ions in cosmic solar radiation. However, this micrometeor has to penetrate the lunar particle to a depth of one micron. The constant solar wind, which is a kind of solar evaporation, does not produce particles with such an energy. But periodic eruptions take place on the solar surface. They cause the ejection of a large amount of material. The particles of clouds emitted then have a much higher energy than those of the constant solar wind. The ratio of one to one thousand, to give you an idea.

So that is the first method. What are its results? What did you learn about the behavior of the Sun in the past?

All ions do not have the same energy. The scars they leave are not all similar. We can thus establish an energy spectrum of solar radiation with heavy energetic ions. Of course acceleration is a delicate phenomenon and the most accelerated ions are the rarest. We will have a slanting spectrum since the number of ions increases as the energy decreases. Well, it seems (and I say seems, for verifications still have to be made), it seems that in the past the angle was less pronounced than today. It implies that the ratio of great energy ions was higher.

In other words, the Sun bombarded harder in the past.

We have some indications of this fact but no certitude. That was the initial research. You talked to me about new methods and other researches.

Our techniques only enabled us to observe one-micron marks, i.e., corresponding to very strong energies. Now with the use of the large microscope at Toulouse, it became possible to go further down. There we could see smaller marks, corresponding to much weaker energies; i.e., we could study the solar wind as constantly emitted and not only the eruptive emissions.

Could you study a natural phenomenon corresponding to the implantation of ions in semiconductors?

Yes, exactly. You know that this implantation only takes place in the superficial strata of crystals. Non-accelerated ions had to remain in the "epidermis" of dust particles. We actually examined one-micron particles with the large microscope. With this device, we are dealing with an object that is quite large and whose details of which can be studied; we then discovered that these particles were surrounded by a kind of superficial pellicle, a shell, which I call an amorphous skin, where thickness corresponds to the depths of implantation of solar|wind ions. So we are able to cover the whole spectrum, from the solar|emission of very energetic to the weakest particles.

Such is the new method. What kind of results are you expecting?

We are working on the generally accepted hypothesis that two types of solar|radiation exist; i.e., eruptive and thermal radiation. The difference in energy between the two is very large and, as a rule, no particles corresponding to this "gap" should exist. It seems that the marks of particles endowed with an intermediate energy have actually been discovered. We think that they could correspond to a new type of radiation whose energy would be between the two known types: we call this radiation superthermal. But here also it is a question of initial observations which are not absolutely certain.

But the possession of such solar|archives stimulates us to ask many other questions. We know, for example, of the existence of a solar|cycle of eleven and a half years. But are there not other cycles? Longer cycles. We have few chances of detecting them with the present measurements. The history of the star must be studied. This is the possibility before us.

Another problem. What was the energy of solar|wind ions in the past? The speed of these particles is now 300 to 800 km/sec. By studying the thickness of the skin of particles taken at different depths we would be able to measure it, since the thickness of the skin represents the depth of implantation, which in turn depends on particle energy. From the evaporation rate of solar|particles, we could deduct a great many things about the functioning of the star at the time considered.

All these extrapolations are attractive as long as you possess an exact time scale. How certain are you concerning the dating of your various samples?

Of course it is a delicate problem. We expected much from the stratigraphy of core samples, taken from the Moon soil. It is a good calendar. But the core sample of Apollo XI was not stratified. This was a catastrophe. Fortunately all the following core samples of Apollo XII, Apollo XIV and Luna XVI had very visible stratifications. Of course we do not know the range of time between two successive strata. We are still in relative time, the "younger" or the "older".

Does N.A.S.A. mention to you the levels where the different core samples come from?

Of course, but I am not greedy, you know. We work with minute quantities. With a hundred milligrams, I have millions of small individual crystals, which are detectors, each deserving individual study. You can see that a little material corresponds to much work. Moreover, the same samples can be studied in common in the consortium. It is indispensable to reconstitute the time scale, for example by studying the implantation of rare gases with Signer in Switzerland.

But this cooperation can bring much more important results. In like manner, I am working with Dolffus on the albedo problem. When we observe the Moon we see bright and dark zones. They have different albedos. Why?

In the albedo function, several parameters can be retained; concentration of ions strongly absorbing light, like titanium; mineralogical composition. For example, since pyroxene is a very dark mineral, plagioclase without iron is brighter.

But we wondered if albedo did not depend on the condition of this superficial, amorphous skin of the particles. The particle forms a multidielectric environment, since the inside does not have the same refraction index as the amorphous skin. There must be a loss of light caused by many internal reflections. So the presence of this amorphous skin would be due to an absorption of the light of the environment. There could be a correlation between the more or less dark appearance of the material and the more or less large number of microcrystals on which solar winds would have formed this amorphous skin.

We tried to see if such a correlation existed. It seems to exist. Consequently, the darker a planetary soil of lunar type, the longer it has been exposed to solar irradiation. I do say "a soil of lunar type". If this correla-

tion can be established, it will be possibly used for the "remote" exploration of Mars, for example, or the asteroids.

We also try to establish relationships between the irradiation of microscopic particles and the resistance of the material to penetration. Here also there seems to be a relationship. The harder the soil, the more irradiated the particles are.

There are also all the researches on the origin of life. We seem to find more carbon or methane on highly irradiated particles. Therefore, we may assume that the light atoms implanted solar wind interact with dust oxygen to make a first prebiological chemical reaction. Here also we have very encouraging results matching those of astrochemistry.

According to you, does the possession of these Moon rocks seem to be the beginning of a very important scientific adventure?

Without any doubt. They will circulate in the international community for years. Yes, there is still more than ten years of work to do on these samples. At the end of this study, two fundamental things will be evident. First, we have never gone as far in research on an object in the history of science. No body has never been studied more than the Moon rocks. No research has ever been as coordinated. Multidisciplinarity has never been led so far. Therefore it is a unique experience which will provide direct results, but which will also give very fruitful indirect results, as long as it is used as a test stand on the world scale for the elaboration of new methods of work. Do not forget the aspect. It is essential, particularly in the training of young researchers.

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